Appendix C
Study Planning and Reporting

C-1. Development of the Hydraulic Study Work Plan

This appendix gives additional details on the preparation of the hydraulic study work plan, a critical step in designing and performing a hydrologic engineering study. Also presented are general reporting requirements for presentation of hydrologic/hydraulic (H & H) studies. As mentioned in Chapter 3, the development of a Hydrologic Engineering Management Plan (HEMP) should occur early in any project or study involving significant hydrologic/hydraulic effort. The HEMP covers all hydrologic and hydraulic effort including sediment studies where appropriate. This section describes the development of such a plan.

a. General considerations. The preparation of a HEMP is not intended to be another layer of review guidance or to put additional burden on the hydraulic engineer. The use of a HEMP should be of great value to an engineer in planning and scheduling hydraulic activities, developing and documenting time and cost estimates, and decreasing the supervisory time required to oversee the effort.

b. Purpose of HEMP. The main purposes of a hydraulic study work plan are to enable the engineer to estimate the overall amount of effort required and the level of detail of that effort, plan the sequencing of H&H activities, determine the interrelationship of the information exchange between H&H and other disciplines and its effect on scheduling and sequencing activities, and identify other items and potential problems. The HEMP is nothing more than a detailed outline of how the responsible hydraulic engineering team proposes to perform the overall hydraulic study. The detail with which the various activities are described should be sufficient to prepare an adequate time and cost estimate for the entire hydraulic study. A well prepared time and cost estimate will facilitate negotiations with project managers. The HEMP should be as detailed as practical, particularly for hydraulic engineers with limited experience. More experienced engineers may prepare less detailed HEMP's. The level of presentation should be up to the hydraulic engineering team which includes the supervisor. In short, the HEMP may take several days to prepare, but its existence will pay continuous dividends throughout the course of the hydraulic study.

c. Level of detail. The HEMP may be as detailed as desired, in terms of outlining specific hydrologic and hydraulic work activities. It usually will parallel the level of the reporting activity, however. Table 3.1 broadly describes the general work processes involved in the various levels of report activities and the HEMP will be similar. The level of HEMP is usually most detailed for the feasibility report stage, since the hydrology and hydraulics need to be "final" form, and the hydraulic design in sufficient detail to provide a firm construction cost and identify the NED plan. Less detailed HEMP's are acceptable in other phases of the planning process such as the reconnaissance, reevaluation, or design memorandum stage. Similarly, in the continuing authority program, the reconnaissance report, being similar to a feasibility report, requires the most detailed HEMP. The sections at the end of this appendix illustrate examples of detailed HEMP's for both a steady and an unsteady gradually varied flow analysis.

d. Determination of the study boundary. As mentioned in Chapter 3, the analysis of a potential project and its effects on the watershed hydrologic, hydraulic, and sedimentation regimes is not confined to the physical limits of the project. The HEMP must address the total (basin-wide) effects of the project. The study boundary could well extend for many miles upstream and downstream of the project boundaries as well as up tributaries to the project stream. The total work to be performed is largely dependent on the study boundary rather than the project boundary. It is important that this fact be recognized and included in the HEMP leading to the study time and cost estimate.

e. Sequence of preparation. The preparation of a HEMP should take place over the first days or weeks of initial study planning activities. Information concerning the necessary H&H activities and level of detail should be obtained from discussions with interdisciplinary team personnel, local interests, evaluation of available data, and examination of potential alternatives.

(1) Objective/problems/alternatives. In the initial phase, the objective of the plan (flood control, navigation, etc.) is known and at least some of the problems associated with achieving this objective will be apparent. One or more alternatives to be evaluated will normally be obvious as well, at least to an experienced hydraulic engineer. These problems and alternatives usually suggest likely computational techniques (gradually varied steady flow, etc.) for an appropriate analysis. These

initial evaluations may be utilized for preliminary development of a HEMP.

(2) Data availability. Hydraulic, topographic, and other data available and required will be identified during the HEMP formulation phase. The determination of the project and study boundaries will allow an estimate of topographic (survey) data needed and form the basis for a later survey request. Available gaged data should be identified as well as information from past hydrologic or hydraulic studies.

(3) Review. Two or more drafts of the HEMP may be appropriate depending on the level of peer review. At a minimum, the engineer's immediate supervisor should thoroughly critique the work plan for completeness and agree with the engineer as to the sequence of activities, level of detail, and method for addressing hydrologic/hydraulic studies and potential alternatives. For particularly complex or controversial projects, Division review may be appropriate.

(4) Time and cost estimate. With the HEMP reviewed and approved, durations can be estimated for the activities and an appropriate personnel cost developed. The time and cost estimate, based on a detailed evaluation of H&H activities, provides the basis for requesting resources.

(5) Periodic updates. The sequence of activities and all the alternatives that require evaluation typically cannot be predicted precisely at the start of a feasibility study, thus some level of contingency funding is necessary. As the study unfolds however, the HEMP should be routinely updated, annually or more frequently, as necessary. At the conclusion of the study, it is worthwhile to again update the overall HEMP so that the knowledge gained from this study will be available for future, similar, efforts. The HEMP is not intended to be a one-shot effort to be developed and forgotten at the start of a hydrologic engineering study. It should be a "road map", leading the hydraulic engineer through the entire study and used on a nearly daily basis.

C-2. Reporting Requirements

a. General. No matter how well the hydraulic engineer has performed a technical analysis, the lack of a complete and well-written report of the work will cast doubt on its validity. The report is written to document the major steps and findings of the hydrologic work and to convince one or more technical reviewers that the final result is the most appropriate one for the study objectives, level of available data, technical analysis, alternatives possible, and the alternative selected.

b. Guidelines. Some general guidelines for preparing the report are:

(1) Format. The hydrologic and hydraulic report is usually presented as an appendix to the main report. Avoid duplication of material in the main body of the report or in previous documents that are still accessible to the review authority. Use cross references as much as possible. Don't use words when the information can be conveyed by tables. Don't use tables when figures or charts can be utilized. Maximize the use of charts, figures, plates and maps in the report. Ensure that locations discussed in the text are clearly indicated on maps. Reference the appropriate figure or map in the text.

(2) Project description. Clearly describe and show the location of the project, its main features, and its function. Describe the impacts of the project both positive and negative on the system hydrology, hydraulics, and sediment regime.

(3) Technical information. Start with the basic data available. Describe the method of analysis selected and why. What key assumptions were made and how were they justified? What are the results of the hydrologic analysis and how do they relate to the plan formulation process? How did you evaluate the sensitivity of results to your assumptions and the consequent effects on project design?

(4) Validity. Remember that you are trying to convince a reviewer of the validity of your technical analysis. An independent analysis should arrive at nearly the same conclusions by following the technical path and thought processes documented in the report. Checklists given in Sections C-3 and C-4 provide questions and information which a reviewer will normally expect to be addressed in the report. Note that not all of these items are the responsibility of the hydraulic engineer.

c. Reporting requirements by study. Hydrologic and hydraulic reporting includes:

(1) Survey reports. These reports are either reconnaissance or feasibility reports.

(a) Reconnaissance reports are limited effort studies to ascertain if a Federal interest is present. If so, the study continues to the feasibility stage. Reconnaissance report hydraulics often consists of the maximum use of existing data and limited hydrologic/hydraulic analysis. The amount of H&H effort and reporting is largely set by the time and funding available for the reconnaissance effort. Four to six months of part-time hydrologic effort is often the maximum available. Consequently, both the HEMP and the reporting level may be minimal. The hydrologic/hydraulic reporting may only be a few pages, sufficient to show the work leading to one or more feasible solutions to be investigated further.

(b) Feasibility reports include complete analyses of the system hydrology and hydraulics, sufficient to determine the NED plan and provide detailed and firm project costs. H&H studies often require two or more years of nearly full time hydraulic engineering effort. Obviously, the level of the HEMP and reporting is much more than the reconnaissance report. Previously addressed guidance in C-2.*b* applies and must be adequately covered. The hydraulic engineer should also closely review ETL 1110-2-230, (1978). This guidance illustrates much of the information desired in a feasibility report, both in general terms and for specific types of flood control projects (reservoir, levee, or channel). Documentation of the effort is normally presented in an hydrology and hydraulics appendix at the end of the main report. All significant H&H work effort should be described and presented, with the sequence outlined in the HEMP providing a starting point for the H&H report outline.

(2) Reevaluation report. This report is the follow-up to the feasibility investigation, normally prepared within a year or two after completion of the survey investigation. Consequently, the hydraulic effort usually consists of updating the hydrology and hydraulics for any changes in the watershed and to confirm that the hydrologic findings of the feasibility investigation are still valid. Hydrologic and hydraulic reporting should reference the survey report as much as practical, with the overall level of reporting much less than the feasibility report. An exception is the case of a reevaluation taking place many years after the feasibility report. Depending on the changes in the watershed, it is possible that the reevaluation would be similar in both technical and reporting detail to the original feasibility report.

(3) Design memoranda. Preconstruction planning reports could include both a general design and one or more feature design memos, depending on the project complexity.

(a) General design memo (GDM). This document provides the detailed engineering and design of the overall project, eventually leading to project construction. An individual levee unit, a reach of channel, or a pumping station would usually require only an individual GDM. The H&H emphasis is on the detailed hydraulic design, as the hydrology, profiles, etc. should be "firm" from previous studies. H&H reporting could be as little as a few pages of text along with accompanying figures and tables, or it could be quite lengthy. Further discussion of the H&H information often needed in a GDM is given in ER 1110-2-1150, pp A2 (1984b). For small projects that are not complex, a GDM may not be required.

(b) Feature design memo. When a project is large and complex or includes many different components, a series of feature design memos (FDM) are often prepared, following completion of the GDM. Individual FDM's may be prepared for each of a series of levee units along a river, on each of several pumping stations within a leveed area, or for major features of a reservoir (for the spillway, the stilling basin, the dam, etc.). Again, the emphasis on the H&H reporting is on detailed hydraulic design, with hydrology, etc. being "firm" from previous effort. If performed, the results of physical model testing and effects on the hydraulic design are included in the appropriate FDM. For simple components with no model testing, H&H reporting could be only a page or two of text with the figures being a part of the detailed drawings prepared for the site layout and construction. Additional discussion on H&H information included in a FDM is given in ER 1110-2-1150, pp. B-1 (1984b).

(4) Plans and specifications. This functional design document is used to bid and construct the project. The usual H&H information included are period of record stage-hydrographs and stage duration curves, so that the contractor may plan the construction activity to take advantage of low water periods. The level of H&H reporting is usually represented only by figures, with little or no text.

(5) Continuing authority program. This umbrella program allows for the planning, analysis, design, and construction of small and noncontroversial projects in a relatively short time frame. The program covers nine different authorities for small flood control, navigation, or shore protection projects. Except for the Section 205 program, the studies are of limited dollar amount for both analysis and construction, and the level of H&H analysis/reporting is also limited. Only the Section 205 authority will be further addressed here. The 205 study normally includes a reconnaissance report and a definite project report (DPR).

(a) The reconnaissance report features a detailed H&H evaluation to firmly establish stage-frequency relations for the economic analysis and clearly demonstrate that a Federal interest is present. The level of analysis and reporting detail is similar to a feasibility report.

(b) The definite project report includes all the necessary analysis and design for the preparation of plans and specifications. Consequently, the level of H&H studies and reporting is similar to a combination of the reevaluation and design memorandum reports. Updates to the hydrology and hydraulics and the detailed hydraulic design are features of the DPR. Hydrologic and hydraulic reporting is presented in a separate appendix to the DPR.

C-3. Hydrologic Engineering Study Checklist

a. Safety. Are the levees, channels, spillways, reservoirs, etc. of adequate height, capacity, storage, or level of protection? Are residual problems (such as flooding) well documented?

b. Function. Is the plan conceptually correct? Will it function in an appropriate manner? Are conclusions supported by a logical sequence of data analyses and deductions?

c. Performance. Will the project description, local cooperation, and operation and maintenance requirements ensure that the plan will continue to perform as planned over the project life? Are all the physical features and institutional arrangements well documented?

d. Engineering. Does the engineering analysis appear appropriate for supporting formulation and design objectives? If not, does it appear that an alternate analysis would result in a different conclusion?

e. Economy. Do the major features of plans generally appear to achieve appropriate project purposes in a cost effective manner? Is each component economically justified?

C-4. Documentation Checklist

a. Rationale. Provide rationale for plan selection, demonstrate that the plan is logical, that it will work, and can be operated and maintained to function correctly.

b. Safety. Address safety considerations: warning time, rate of rise, consequences of exceeding design, etc.

c. Goals. Establish and describe project purposes and area benefitted.

d. Scope. Describe all related features (including real estate), not just what is proposed for construction.

e. Performance. Provide project output, performance levels, and capabilities in economic and physical terms including residual flooding up to the Standard Project Flood.

f. Operating requirements. Describe operational requirements, personnel and equipment, and any constraints (such as warning time) under which the plan must be operated.

g. Cost estimates. Provide reasonable estimates of first cost and OM&R cost.

h. Institutional provisions. Establish legal and institutional arrangements for construction, OM&R, etc.

i. Plans. Identify the NED plan (maximum net economic benefits), Environmental Quality (EQ) impacts, and mitigation; justify departures from NED.

j. Information. Provide design parameters to achieve *c* and *e* above: e.g.; pump head capacity, location of initial levee overtopping, time to close gates, etc. In general, prepare, document, and provide robust, defensible, plan and design information.

k. Consensus. Build public and institutional consensus.

C-5. Example Detailed Hydrologic Engineering Management Plan for a Feasibility Study (Flood Damage Reduction using HEC-1 and -2)

This sample HEMP would be appropriate for the hydrologic and hydraulic analyses associated with a typical Corps feasibility report for an urbanizing watershed. The intent of the hydrologic engineering analysis would be to determine existing and future stage-frequency relationships at all key points in the study area, along with flooded area maps by frequency. This analysis would be performed for the without project condition and for various flood reduction components which are considered feasible for relief of the flood problem.

a. Preliminary investigations. This initial phase includes a literature review of previous reports, obtaining the available data and requesting additional information needed to perform the investigation.

(1) Initial preparation.

(a) Confer with the other disciplines involved in the study to determine the objectives, the H&H information requirements of the study for other disciplines, study constraints, etc.

(b) Scope study objectives and purpose.

(c) Review available documents such as:

1. Previous Corps work.
2. USGS reports.
3. Local studies.
4. Other.

(d) Obtain hydrologic (historic and design discharges, discharge-frequency relationships, etc.) and hydraulic (high water marks, bridge designs, cross sections, etc.) data from, for example:

1. Local agencies.
2. State.
3. Federal (Corps, SCS, USBR, USGS, Federal Highway, NWS, etc.).
4. Railroads.
5. Industries.
6. Other.

(e) Scope major hydrologic and hydraulic activities.

(f) Prepare Hydrologic Engineering Management Plan.

(2) Obtain study area maps; from, for example:

(a) USGS quads.

(b) Aerial photographs.

(c) County highway maps.

(d) Others.

(3) Estimate location of cross sections on maps (floodplain contractions, expansions, bridges, etc). Determine mapping requirements (orthophoto) in conjunction with other disciplines.

(4) Field reconnaissance. Interview local agencies and residents along the stream, review newspaper files, etc. for historic flood data (high water marks, frequency of road overtopping, direction of flow, land use changes, stream changes, etc.). Document names, locations, and other data for future reference. Take photographs of bridges, ongoing construction, hydraulic structures, and floodplain channels and overbank areas at cross section locations.

(5) Determine initial estimate of *n* values for use in water surface profile computations.

(6) Write survey requirements including mapping requirements, cross section locations, and high water marks.

b. Development of basin model. This phase of the analysis involves selection of historic events to be evaluated, development of runoff parameters from gaged data (and/or regional data from previous studies) to be used for ungaged basins, and calibration of the basin model to historic flood events. This step assumes that at least some recording stream gage data in or near the study watershed are available.

(1) Optimization of runoff parameters.

(a) Select historic events to be evaluated based on available streamflow records, rainfall records, high water marks, etc.

(b) From USGS rating curves and stage versus time relationships for each event, develop discharge hydrographs at each continuously recording stream gage. Estimate peak discharge from flood crest gages.

(c) Develop physical basin characteristics (drainage areas, slope, length, etc.) for the area above each stream gage.

(d) Select the computation time interval (Δt) for this and subsequent analyses. It must define adequately the peak discharge of hydrographs at gages, consider routing reach travel times, have three to four points on the rising limb of the smallest subarea unit hydrographs of interest, and consider types of alternatives and future assessments.

(e) Using all appropriate rain gages (continuous and daily), develop historic storm patterns that correspond to the selected recorded runoff events for the basins above the stream gages. For average subarea totals use isohyetal maps; for temporal distributions use weightings of nearby recording rain gages.

(f) Determine optimized unit hydrograph and loss rate parameters for each event at each stream gage.

(g) Make adjustments for better and more consistent results between events at each stream gage, including starting values of parameters and rainfall patterns (different weightings of recording rain gages).

(h) Fix most stable parameters and rerun.

(i) Adopt final unit hydrograph, loss rate, and base flow parameters for each gaged basin.

(2) Delineation of subareas. Subareas are delineated at locations where hydrologic data are required as discussed below.

(a) Index locations where economic damage computations are to be performed.

(b) Stream gage locations.

(c) General topology of the stream system:

1. Physical characteristics of the basin.
2. Major tributaries.
3. Significant changes in land use.
4. Significant changes in soil type.
5. Other.

(d) Routing reaches.

(e) Location of existing physical works (reservoirs, diversions, etc.) and potential locations of alternate flood reduction measures to be studied.

(3) Subarea rainfall-runoff analysis of historic events.

(a) Subarea rainfall: Average subarea rainfall -- from isohyetal maps; temporal distribution -- weighted in accordance with information from nearby recording rain gages.

(b) Average subarea loss rates: Use adopted values from optimization analyses, previous studies of similar basins in the region, or other information.

(c) Unit hydrograph parameters are obtained from relationships based on optimization results at stream gages and physical basin characteristics, previous regional study relationships of unit hydrograph parameters and physical basin characteristics, from similar gaged or known basins, or from judgment if no data is available.

(4) Channel routing parameters.

(a) Modified Puls storage-outflow relationships derived from water surface profile computations (HEC-2).

(b) Optimized from stream gage data (HEC-1).

(c) Adopted parameters from previous studies, experience, etc.

(d) Muskingum-Cunge (need only 8-point sections and *n*-values).

(5) Reservoir Routing (if uncontrolled reservoirs are present). This type of routing must be performed where storage has a significant effect on reach outflow values, with reservoirs being the most notable example. However, one must also apply these techniques where physical features warrant; such as, roads crossing a floodplain on a high fill, especially where culverts are used to pass the flow downstream.

(a) Develop area-capacity data (elevation-area-storage relationships).

(b) Develop storage-outflow functions based on outlet works characteristics.

(6) Including the routing information of part *c* below, generate historic runoff hydrographs at locations of interest by combining and routing each flood through the system.

c. Hydraulic studies. These studies are used to determine water surface profiles, economic damage reaches, and modified Puls channel routing criteria.

(1) Prepare water surface profile data.

(a) Cross sections (tabulate data for each section).

(b) Make cross sections perpendicular to flow.

(c) general, sections should be typical of reaches upstream and downstream of the cross section; however, sections that define hydraulic controls are also needed.

(d) velop effective flow areas. If modified Puls routing criteria are to be determined from water surface profile analyses, the entire section must be used (for storage) with high *n* values in the ineffective flow areas. May need to adjust volumes to account for actual flood-plain storage.

(e) fine *n* values from field reconnaissance, from analytical calculation, and/or comparison with *n* values determined from other similar streams.

(f) Bridge/culvert computations. Estimate where floods that are being studied will reach on each bridge and select the normal bridge method, special bridge method, or special culvert option. Provide cross sections above and below bridges/culverts to model effective bridge flow (i.e. use artificial levees).

(2) Proportion discharges based on hydrologic analyses of historic storms and plot peak discharge versus river mile. Compute a series of water surface profiles for a range of discharges. The analysis should start below the study area so that profiles will converge to correct elevations at the study limits. May want to try several starting elevations for the series of initial discharges.

(3) Manually check all swellheads that are greater than 3 feet.

(4) The results are a series of rating curves at desired locations (and profiles) that may be used in subsequent analyses. Additional results are a set of storage versus outflow data by reach; which, along with an estimate of hydrograph travel time, allow the development of modified Puls data for the hydrologic model.

d. Calibration to historic events. This study step concentrates on improvement of the hydrologic and hydraulic models by acceptable replication of actual historic events, thereby gaining confidence that the models are reproducing the real-world situation.

(1) Hydrologic model.

(a) Check computed hydrographs against recorded data, make adjustments to model parameters and rerun the model.

(b) If no stream gages exist, check discharges at rating curves developed from water surface profiles with high water marks.

(2) Hydraulic model. Adjust the model to correlate with high water marks by ± 1 foot (rule of thumb--may not be applicable for all situations).

(3) Adopt hydrologic and hydraulic model parameters for hypothetical frequency analysis.

e. Frequency analysis for existing land use conditions. The next phase of the analysis addresses how often specific flood levels might occur at all required points in the study watershed. This operation is usually done through use of actual gage data (when available) to perform statistical frequency analyses and through hypothetical storm data to develop the stage-frequency relationships at all required points.

(1) Determine and plot analytical and graphical frequency curves at each stream gage. Adopt stage/discharge frequency relations at each gage. Limit frequency estimate to no more than twice the data length (i.e., 10 years of data should be used to estimate flood frequencies no rarer than a 20-year recurrence interval event).

(2) Hypothetical storms.

(a) Obtain hypothetical frequency storm data from NOAA HYDRO 35, NWS TP40 and 49 and NOAA Atlas-2 for Western states, or from appropriate other sources. Where appropriate, develop the Standard Project and/or the Probable Maximum Storm.

(b) Develop rainfall pattern for each storm, allowing for changing drainage area within the watershed model.

(3) Develop corresponding frequency hydrograph throughout the basin using the hydrologic model.

(4) Calibrate model of each frequency event to known frequency curves. Adjust loss rates, base flow, etc. The frequency flows at ungaged areas are assumed to correlate to calibrated frequency flows at gaged locations.

(5) If no streamflow records or insufficient records exist to develop analytical frequency curves, use the following procedure:

(a) Obtain frequency curves from similar nearby gaged basins.

(b) Develop frequency curves at locations of interest from previous regional studies (USGS, COE, State, etc.).

(c) Determine frequency hydrographs for each event from the hydrologic model and develop a corresponding frequency curve at the locations of interest throughout the basin.

(d) Plot all the frequency curves (including other met hods if available) and, based on engineering judgment, adopt a frequency curve. This curve may actually be none of the above, but simply the best estimate based on the available data.

(e) Calibrate the hydrologic model of each frequency event to the adopted frequency curve. The frequency curve at other locations may then be determined from the calibrated model results.

(6) Determine corresponding frequency water surface elevations and profiles from the rating curves developed by the water surface profile evaluations.

f. Future without project analysis. When hydrologic and/or hydraulic conditions are expected to significantly change over the project life these changes must be incorporated into the H&H analysis. Effect of urbanization on watershed runoff is the usual future condition analyzed.

(1) From future land use planning information obtained during the preliminary investigation phase, identify areas of future urbanization or intensification of existing urbanization.

(a) Types of land use (residential, commercial, industrial, etc.).

(b) Storm drainage requirements of the community (storm sewer design frequency, on-site detention, etc.).

(c) Other considerations and information.

(2) Select future years in which to determine project hydrology.

(a) At start of project operation (existing conditions may be appropriate).

(b) At some year during the project life (often the same year as that at which land use planning information is available).

(3) Adjust model hydrologic parameters for all subareas affected by future land use changes.

(a) Unit hydrograph coefficients reflecting changed time-to-peak and possible decreased storage.

(b) Loss rate coefficients reflecting changed imperviousness and soil characteristics.

(c) Routing coefficients reflecting changed travel times through the watershed's hydraulic system.

(4) Operate the hydrologic model and determine revised discharge-frequency relationships throughout the watershed for future without project conditions.

g. Alternative evaluations. For the alternatives jointly developed with the members of the interdisciplinary planning team, modify the hydrologic and/or hydraulic models to describe the effects of each alternative (individually and in combination) on flood levels. Alternatives can include both structural (reservoirs, levees, channelization, diversions, pumping, etc.) and nonstructural (flood forecasting and warning, structure raising or relocation, floodproofing, etc.). Considerably less H&H effort is necessary for modeling nonstructural alternatives compared to structural.

(1) Consider duplicating existing and future without H&H models for individual analysis of each alternative or component.

(2) Structural components are usually modeled by modifying storage outflow relationships at the component location and/or modifying hydraulic geometry through the reach under consideration. The charts given in Chapter 3 contain more information on the analysis steps for each of the following alternatives:

(a) Reservoirs--adjust storage-outflow relationships based on spillway geometry and height of dam.

(b) Levees--adjust cross-sectional geometry based on proposed levee height(s). Evaluate effect of storage loss behind levee on storage-outflow relationships and determine revised discharge-frequency relationships downstream, if considered significant.

(c) Channels--adjust cross-sectional geometry based on proposed channel dimensions. Evaluate effect of channel cross section and length of channelization on floodplain storage, modify storage-outflow in reach and determine revised downstream discharge-frequency relationships, if considered significant.

(d) Diversions--adjust the hydrologic model for re duced flow downstream of the diversion and identify where diverted flow rejoins the stream (if it does).

(e) Pumping--adjust hydrologic model for various pumping capacities to be analyzed.

(3) Evaluate the effects of potential components on sediment regime.

(a) Qualitatively--for initial screening.

(b) Quantitatively--for final selection.

(4) Nonstructural components.

(a) Floodproofing/structure raises--elevations of design events primarily.

(b) Flood forecasting--development of real-time hydro logic model, determination of warning times, etc.

(5) Alternative evaluation and selection is an iterative process, requiring continuous exchange of information between a variety of disciplines. An exact work flow usually cannot be developed for most projects, thus evaluation of alternatives could be relatively straightforward or quite complex, requiring numerous re-iterations as more cost and design information is known and project refinements are made. This is usually the area of the HEMP requiring the most time and cost contingencies.

h. Hydraulic design. Hydraulic design must be included with the sizing of the various components, both to operate H&H models and to provide sufficient information for design and costing purposes.

(1) Reservoirs--dam height, spillway geometry, spillway cross section, outlet works (floor elevation, length, appurtenances, etc.), scour protection, pool guidetaking line, etc.

(2) Levees--levee design profile, risk analysis, interior drainage requirements, etc.

(3) Channels--channel geometry, bridge modifications, scour protection, channel cleanout requirements, channel and bridge transition design, etc.

(4) Diversions--similar to channel design, also diversion control (weirs, gates, etc.).

(5) Pumping--capacities, start-stop sump elevations, sump design, outlet design, scour protection, etc.

(6) Nonstructural--floodproofing or structure raise elevations, flood forecasting models, evacuation plan, etc.

i. Prepare H&H report in appropriate level of detail. The last step is to thoroughly document the results of the technical analyses in report form. Hydrologic and hydraulic information presented will range from extensive for feasibility reports to minimal for most FDM's.

(1) Text.

(2) Tables.

(3) Figures.

C-6. Generic Hydraulic Study Work Plan for Unsteady, Gradually-Varied Flow Analysis (TABS-2)

There exist several unsteady flow models, such as DAMBRK, and DWOPER developed by Dr. D. Fread of the National Weather Service, TABS-2 developed by WES, and UNET developed by Dr. R. Barkau, etc. TABS-2 will be used as an example for a HEMP.

a. TABS-2. The Open-Channel Flow and Sedimentation Model (TABS-2) is a two-dimensional finite element model managed by the Waterways Experiment Station, Corps of Engineers, that calculates water surface elevations, current patterns, sediment erosion, transport and deposition, and the resulting bed-surface elevations. The three basic components of the system are:

(1) "Two-Dimensional Model for Open-Channel Flows," RMA-2.

(2) "Sediment Transport in Unsteady Two-Dimensional Flows, Horizontal Plane," STUDH.

(3) "Two-Dimensional Model for Water Quality," RMA-4.

One, two, or all three components may be necessary for a specific project. This generic HEMP will assume that only the hydraulic and sediment models are necessary.

b. Preliminary investigations. The initial phase includes a literature review of previous reports, obtaining the available data, and requesting any additional information needed to perform the investigation.

(1) Initial preparation.

(a) Confer with the other disciplines involved in the study to determine the objectives, H&H information requirements of the study for other disciplines, study constraints, etc.

(b) Review available documents, such as:

1. USGS water-data reports for the State.
2. Previous Corps work.
3. Local studies
4. Other.

(c) Obtain hydrologic and hydraulic data (period of record routing, discharge-stage relationships, sediment concentrations, water temperatures, wind velocities, etc.) from:

1. Local agencies.
2. State
3. Federal (USGS, SCS, USBR etc.)
4. Railroads.
5. Industries.
6. Other.

(d) A data collection program may need to be established for the study area. Obtain sediment data for the project reach (silt, clay, sand, gravel, cobbles, boulders, rocks, etc.), composition of sediment (fine, medium, coarse, etc.), layer thickness of soil classifications (alluvium, outwash, ice contact, etc.). These data can usually be obtained from the sources cited above.

(2) Obtain study area maps.

(a) County highway maps.

(b) USGS quads.

(c) Aerial photographs.

(d) Others.

c. Development of hydraulic model (RMA-2).

(1) Generation of grid/mesh for the project.

(a) Define the study area on the largest scale map available. Draw a boundary completely around it. Make sure that the downstream and the upstream boundaries are well separated from any point of special interest. If using a grid generator and/or a digital terrain model, steps (b) - (f) may be automated.

(b) Lay out the nodes, i.e., the computation points, and link them together using quadrilateral or triangular shapes, to create the elements for the mesh. Avoid elements that are too large, especially at, or near, any point of special interest.

(c) Number the elements.

(d) Number the nodes counterclockwise, as required by TABS-2.

(e) Digitize the area within, and including, the boundary into x, y, z-coordinates at the nodes.

(f) Determine the slopes of the boundary at the boundary nodes (if using curved-sided elements).

(g) Plot the grid. Make sure that the elements are well-formed and that the boundaries match the prototype.

(h) Correct and adjust the node locations and bottom elevations until the representation of the topography/bathymetry is satisfactory.

(i) Analyze the subsequent output data. Check all the elements to make sure that they are well defined. Make all the corrections, if any, and redo step (a) until the model is completely sanitized.

(j) Give special attention to the list of the boundary nodes (if given), as they may be needed in identifying the external boundary nodes for hydrodynamics computations.

(2) Hydrodynamics.

(a) Plot the hydrograph of flows for the period under consideration.

(b) Select the computation time interval. Experiment to find the optimum value. An interval too large or too small can cause problems.

(c) Select the proper type of boundary conditions (head, flow, velocity, slip boundary, etc.) and their proper combinations, this is not trivial. Discharge at the upstream boundary, and water surface elevation at the downstream boundary are the boundaries in most river cases.

(d) Select roughness (*n* values) and turbulent exchange coefficients. These can vary spatially; refer to model user documents and past experience for guidance on selection.

(e) Create RMA-2 control file and make a test run for steady flow, using zero flow first.

(f) Analyze the output, make all needed corrections, and make more test runs until the test results are satisfactory. Try dynamic simulations only if needed and the steady state results are acceptable.

(g) Plot model results. Check the direction and mag nitude of the velocity vectors.

(h) Run RMA-2 calibration tests. Compare model results against prototype data and/or physical model test data. Calibrate model coefficients.

(i) Run RMA-2 base test.

d. Development of sedimentation model (STUDH).

(1) Data development.

(a) Obtain gradation curves for the channel material from sources previously mentioned, and select the representative grain size.

(b) Obtain the sediment concentration data from sourc es previously mentioned. Evaluate the sediment concentrations at the boundaries, recalling that concentrations too low may cause erosion and that concentrations too high may cause deposition.

(c) Know the type of sediment you are dealing with. i.e., silt, clay sand, etc., alone or in combination.

(d) Estimate the fall velocity. The Stokes diagram may be used to evaluate the fall velocity of sediment particles.

(e) Select the turbulence exchange coefficients and diffusion coefficients. Experiment to find the best coefficients for your situation.

(f) Evaluate the roughness coefficients.

(g) Select the computation time interval. Experiment to find the best value for your specific situation. An interval of 15 minutes has often been found satisfactory.

(2) Model operation.

(a) Run STUDH.

(b) Analyze the output. Correct all errors. Check for unreasonable erosion or deposition. Rerun, if necessary.

(c) Compare the results with prototype data and/or physical model test data. Calibrate the model.

(d) Use postprocessor programs to plot or tabulate results.

(e) Make a verification run using a separate data set.

(f) When verification is judged successful, adopt mod el for production runs.

e. Project analysis (both models).

(1) Perform the base test run.

(2) Perform the base test with project test run.

(3) Evaluate and make the adjustments necessary for comparison of with and without project conditions.

f. Prepare H&H report in appropriate level of detail.

(1) Text.

(2) Tables.

(3) Figures.